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Early experiments of JAERI fuel cleanup system at the tritium systems test assembly

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The Tritium Process Laboratory (TPL) at the Japan Atomic Energy Research Institute (JAERI) has developed a Fuel Cleanup System (FCU) which accepts simulated fusion reactor exhaust and produces pure hydrogen isotopes and tritium-free waste. Under the collaboration program of USDOE and JAERI, an integrated process, the "JAERI Fuel Cleanup System" (JFCU) was designed and fabricated for testing at the Tritium Systems Test Assembly (TSTA) as a major subsystem of the simulated fusion fuel cycle. The JFCU has the capability to continuously process a mixture of hydrogen isotopes and impurities of 15 mol/h. The major components are: a palladium diffuser for hydrogen isotopes purification, a catalytic reactor for oxidation of tritium in impurities, cold traps for separation of tritiated water to produce exhaust containing a very low level of tritium, a ceramic electrolysis cell for decomposition of tritiated water, and zirconium–cobalt beds for hydrogen isotopes storage. In early 1990, the JFCU was installed in the TSTA and preliminary testing without tritium was initiated. Components such as the palladium diffuser, cold traps, catalytic reactor, scroll pump and electrolysis cell were tested independently as well as in the integrated process tests.

1. Introduction

The Tritium Process Laboratory (TPL) of the Japan Atomic Energy Research Institute (JAERI) has developed a fuel cleanup system (FCU) that processes plasma exhaust to recover pure hydrogen isotopes for the Isotope Separation System (ISS) and exhausts impurities as a stream containing a low level of tritium. The process features purification of hydrogen isotopes by selective permeation through a palladium alloy membrane and by the recovery of hydrogen using an oxidation-trapping-vapor phase electrolysis cycle. Component studies began in the early 1980s and development and testing without tritium was performed in the TPL in the period of 1981–1986 [1,2]. Tritium testing of the components was performed under the US–Japan collaboration program at the Tritium Systems Test Assembly (TSTA) in the Los Alamos National Laboratory (LANL) [3] to verify the fundamental characteristics, compatibility with tritium, effects of impurities, and long-term operability and reliability. The first integrated loop of the FCU process was installed in the TPL and successfully tested with a large amount of tritium [4] beginning in 1988. A number of tests were performed with simulated plasma exhausts and the process was proved to be feasible as a stand-alone subsystem of the fusion fuel cycle.

Based on these results, the complete FCU subsystem was developed and designed by JAERI for full scale demonstration of plasma exhaust reprocessing in a fusion fuel loop. The objectives of the tests are to study the integrity of the process, interaction with other subsystems, reliability and controllability, and process response under normal and off-normal conditions. The system, called JFCU, was installed in the TSTA in early 1990 and a number of non-tritium tests were conducted. First tritium testing was started in late March, 1991.

The present paper describes the features and recent results of the JFCU tests. Some components such as the scroll pump and the palladium diffuser revealed interesting characteristics that should be studied further with tritium.

2. System description

The JFCU processes simulated plasma exhaust that contains major Q_2, (Q stands for any mixture of H, D,

and T) and up to 15% of impurities such as helium, water, methane and ammonia. The inlet Q_2 flow is 15 mol/h, the same as the original design feed flow rate for the existing TSTA FCU [5], and 1/5 of the throughput for ITER. It must meet all performance requirements of the existing TSTA FCU that is based on a more conservative technology and has been operated in an integrated loop run [6]. Figure 1 shows a simplified flow diagram of the JFCU.

A palladium diffuser is used for the purification of the Q_2 to be sent to isotope separation because of its continuous nature and expected high purity of the product. The permeated side of the palladium membrane is evacuated by a scroll pump to drive permeation and compress the product to the desired pressure for supply to the ISS.

The bleed stream from the diffuser that contains tritiated impurities and unpermeated Q_2 is then treated in the Catalytic Reactor–Cold traps–Electrolysis Cell train for tritium recovery. For recovery of tritium from the impurity stream, conventional oxidation-cold trapping was chosen for its proven capability to produce a tritium-free exhaust stream. This process is also expected to recover tritium from some unknown species such as higher hydrocarbons. The Catalytic Reactor operates at 500 °C so that the conversion ratio of methane will be higher than 10^6.

The tritiated water is then frozen out at the Cold Traps and only tritium-free species are discharged. The Cold traps are operated in a cycle of trapping, regeneration and precooling. They are automatically switched-over every hour in accordance with the three steps in the cycle.

Tritiated water vapor from the heated Cold trap is decomposed in the Ceramic Electrolysis Cell (CEC) that utilizes the oxygen ionic conductivity of zirconia ceramic. This method was selected because of its minimal inventory, continuous nature, superior capabililty of separation of by-product oxygen, and simpler process configuration. Exhaust from the CEC is fed back to the system inlet and the recovered tritium joins the product stream while the carrier for the Cold Trap regeneration recirculates the loop.

The process is designed to have minimal tritium inventory and to be operated continuously without generation of any solid waste.

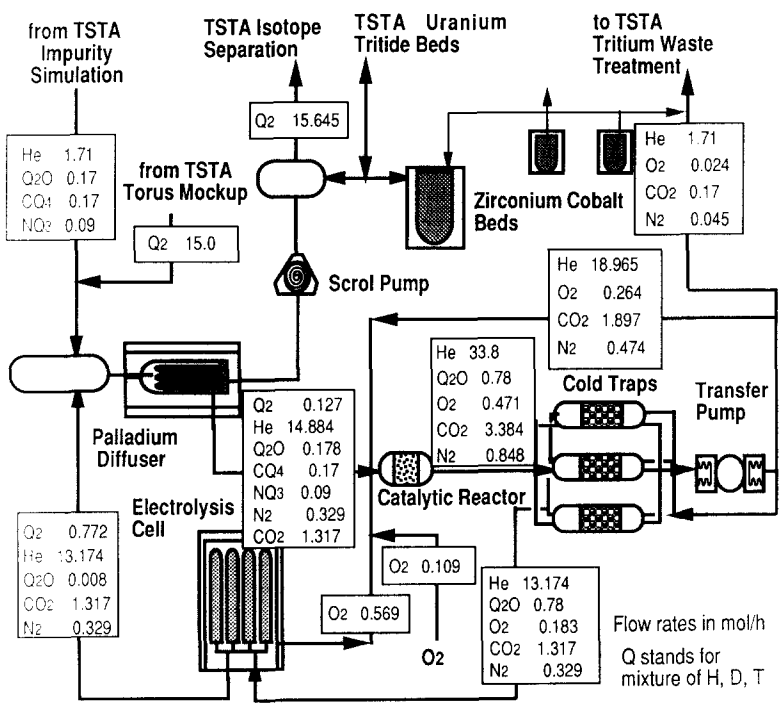

Fig. 1. Flow diagram of the JAERI fuel cleanup system.

The apparatus is installed in a glovebox of about 5 m × 1.2 m × 2 m. Monitors and the control program for the secondary containment were supplied by TSTA.

3. Experiments and results

3.1. Palladium diffuser tests

Experiments with this apparatus have been performed since April 1990. The permeability of hydrogen isotopes was measured with the palladium diffuser-scroll pump loop. Figure 2 shows the initial permeation characteristics of hydrogen through the diffuser and the effect of cleaning treatment of the membrane. The permeation flux showed a linear relation with the differential square-root of pressure across the membrane. Poor permeability was observed especially when the pressure at the permeated side of the membrane is low. It was suspected that contamination of the surface of the membrane slows down the desorption of hydrogen from the surface and reduces permeability [7]. Baking of the membrane at 450 °C in oxygen followed by hydrogen reduction improved the permeability.

Figure 3 summarizes the permeability of deuterium through the cleaned membrane. The result indicates that a satisfactory processing rate with tritium can be expected, according to the isotopic ratio of permeability obtained in the previous studies. The linear relationships in the figure showed offsets as a function of the pressure at the permeated side. It is suggested that the reduction of concentration of hydrogen in the bleed, that is controlled by the permeation in the low (partial) pressure region, may not proceed as expected in the high pressure region.

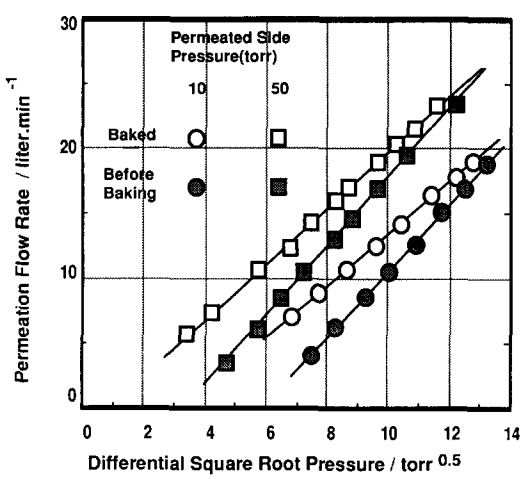

Fig. 2. Permeabilities of pure hydrogen isotopes through the palladium diffuser before and after activation. The permeation flow rate is plotted against the differential square-root of pressure across the diffuser.

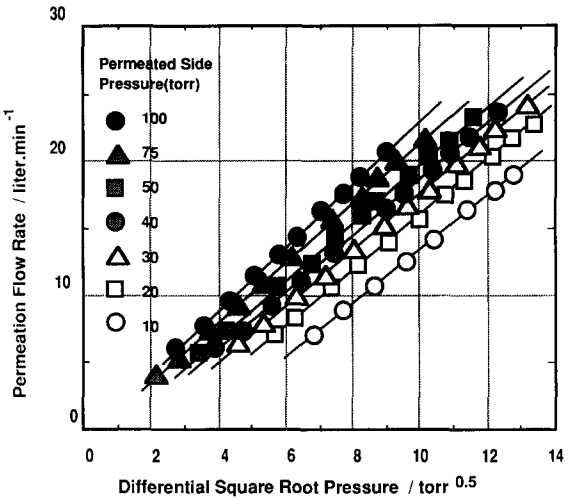

Fig. 3. Effect of the pressure at the permeated side of the diffuser on the permeation characteristics of deuterium through the membrane.

3.2. Scroll pump tests

A Normetex scroll pump evacuates the permeated side of the palladium diffuser, and compresses purified hydrogen isotopes to approximately 800 Torr for supply to the ISS. It has been pointed out that some oil-free vacuum pumps have poorer pumping characteristics with light gases [8]. Compression of hydrogen, deuterium and helium was measured as a function of throughput in the scroll pump.

Figure 4 summarizes the pumping characteristics of hydrogen with the scroll pump. Discharge pressure strongly affects the pumping capacity. It is apparently caused by the poor compression of light gas by the pump, probably due to the mechanical properties of the gas. Comparison of hydrogen, deuterium and helium in fig. 5 indicates that there is a drastic difference among pumping characteristics for these gases. Although deuterium and helium have the same molecular weights, deuterium was more difficult to pump. It was revealed that the scroll pump expected to compress hydrogen isotopes from 5 Torr to 800 Torr at a throughput of 6 l/min will not meet the requirement.

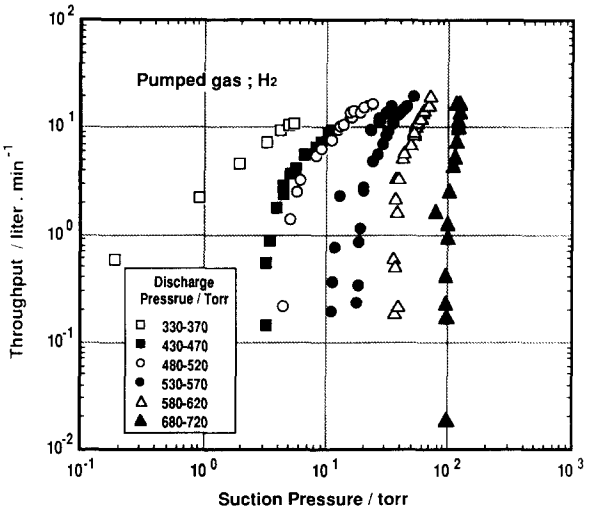

Fig. 4. Pumping characteristics of hydrogen with the scroll pump as a function of discharge pressure. Throughput is plotted against suction pressure.

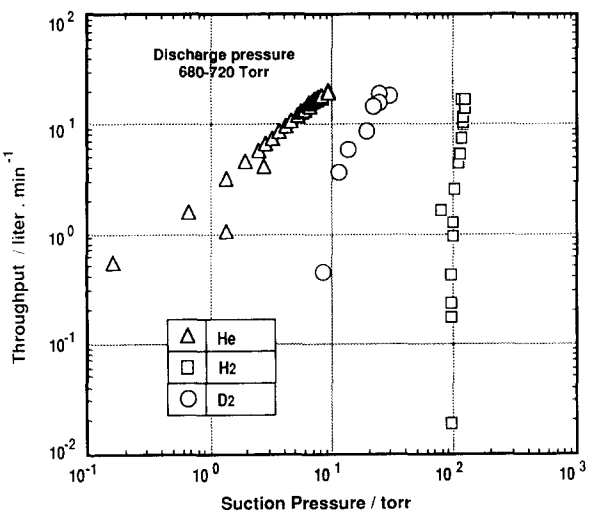

Fig. 5. Comparison of pumping characteristics for hydrogen, deuterium and helium in the scroll pump.

A metal bellows pump MB-601 (Metal Bellows Co.) was installed on the discharge side of the scroll pump to improve the compression. Figure 6 shows the effect of the metal bellows pump on the characteristics. Both the compression ratio and ultimate pressure of the system were improved and the designed throughput was met with either deuterium or hydrogen. Further testing of these pumps with pure tritium and mixtures is scheduled in one of the first tritium runs of JFCU.

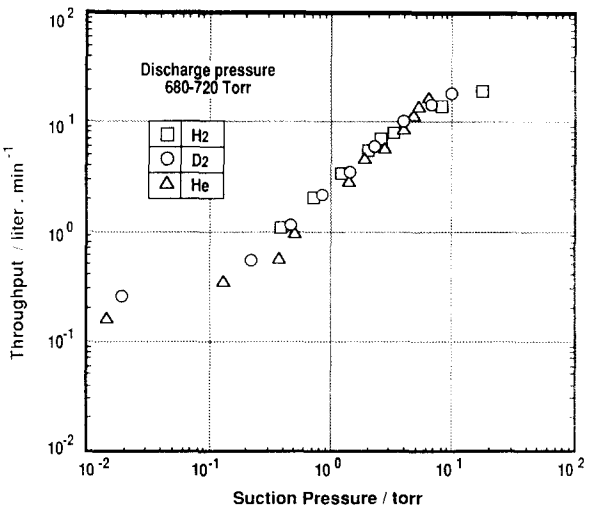

Fig. 6. Pumping of hydrogen, deuterium and helium by a combination of a metal bellows pump and a scroll pump.

3.3. Integrated test with deuterium

The total performance tests of the JFCU were conducted with deuterium-impurity mixtures. Purification of deuterium, oxidation of impurities (CH_4 and NH_3), trapping and decomposition of water, gas analysis by the GC system, and supply and recovery of deuterium

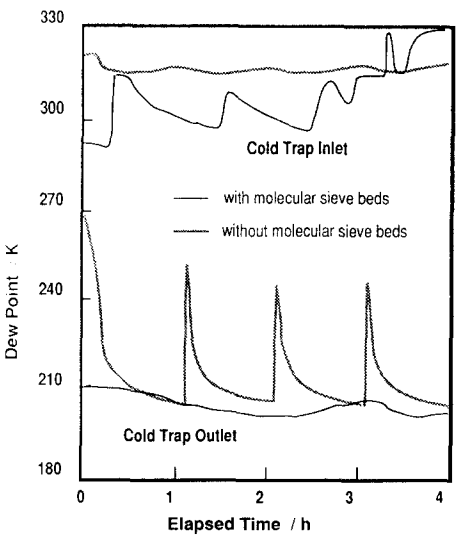

Fig. 7. Moisture trapping by the cold traps of the JFCU. Effect of the small molecular sieve beds at the outlet of each traps is shown.

with the large zirconium–cobalt bed were successfully tested in an interlinked process.

A problem was uncovered in the cold traps and some modifications were attempted. During the integrated test, humidity spikes at the outlet of the trap were observed when the traps were switched. Rough estimation indicates that the order of 10 Ci/day will be discharged to TWT if the carried over humidity is DTO.

Installation of a baffle or filter in the traps, control of the pressure and flow rate across the traps, or change of the valve sequence did not improve the trapping efficiency. Small molecular sieve beds are finally installed at the outlet of the traps. The result is shown in fig. 7. The humidity spikes at the outlet of the trap in switching were completely removed by this treatment, and the regeneration of the beds is completed during the one hour cycle.

4. Conclusion

The JAERI Fuel Cleanup System (JFCU) was developed as a full-scale subsystem of the fusion fuel cycle to be tested in the TSTA under a US–Japan collaboration program. Initial testing with hydrogen and deuterium showed the process works well and is ready for tritium operation. Some insufficient functions were revealed and modifications were made on the hydrogen pumping system and cold traps. The process began tritium operation in March 1991. The result of tests with simulated fusion fuel in an integrated loop is expected to demonstrate the tritium technology needed for the next fusion devices.

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